TECTONIC HISTORY OF THE TERRESTRIAL PLANETS

FINAL TECHNICAL REPORT

TO THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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This is a final summary report of research conducted under NASA Grant NSG-7297, "Tectonic History of the Terrestrial Planets." Research support under this grant was provided incrementally over a 13-year period, from October 1, 1976, through September 30, 1989.

Over its duration, this grant has supported the research, on behalf of the NASA program in Planetary Geology and Geophysics, of one senior investigator, three research staff members, 10 graduate research assistants, and a number of undergraduate assistants and supporting staff. The Principal Investigator was S.C. Solomon; research staff members included G. Consolmagno, R.E. Grimm, and T. Matsui. Graduate students included S.R. Bratt, R.P. Comer, R.E. Grimm, J.L. Hall, P.Y. Huang, P.J. McGovern, N. Namiki, S.K. Stephens, C.H. Thurber, and K. Yomogida. Several of these last two groups of individuals are now investigators in their own right in the research programs of NASA and other agencies.

It is impossible in a single brief summary to convey the full range of research results that have come from this project over the last 13 years. The sweep of subjects covered ranges widely over the broad areas of the thermal and tectonic evolution of the terrestrial planets. A full list of all publications supported by this grant follows the text of this report. The list includes 48 published journal articles, 2 papers currently in press, 3 chapters of books, 4 M.I.T. theses, one technical report, and 107 published abstracts and extended abstracts. All of these publications have been submitted separately to NASA at the time of publication or submission and as part of annual progress reports.

CUMULATIVE LIST OF PUBLICATIONS SUPPORTED BY NASA GRANT NSG-7297

Abe, Y., and T. Matsui, Early evolution of the Earth: Accretion, atmosphere formation, and thermal history, in *Proc. Lunar Planet. Sci. Conf. 17th, J. Geophys. Res., 91,* E291-E302, 1986.

Bratt, S. R., The structure and thermal tectonics of planetary lithospheres: Mid-ocean ridges and lunar impact basins, Ph. D. thesis, Massachusetts Institute of Technology, Cambridge, 386 pp., 1984.

Bratt, S. R., S. C. Solomon, and J. W. Head, The evolution of multi-ringed basins: Cooling, subsidence and thermal stress, in *Lunar and Planetary Science XII*, 109-111, Lunar and Planetary Institute, Houston, Tex., 1981.

Bratt, S. R., S. C. Solomon, and J. W. Head, The relationship of cooling, subsidence, and thermal stress to the topography and tectonics of multi-ringed basins, in *Papers Presented to the Conference on Large Body Impacts and Terrestrial Evolution*, p. 6, Lunar and Planetary Institute, Houston, Tex., 1981.

Bratt, S. R., S. C. Solomon, and J. W. Head, The deep structure of lunar basins: Implications for excavated cavity volumes, in *Lunar and Planetary Science XIII*, 67-68, Lunar and Planetary Institute, Houston, Tex., 1982.

Bratt, S. R., S. C. Solomon, and J. W. Head, Subsurface heating during impact basin formation: Constraints from thermal contraction and thermal stress, in *Lunar and Planetary Science XVI*, 91-92, Lunar and Planetary Institute, Houston, Tex., 1985.

Bratt, S. R., S. C. Solomon, and J. W. Head, The evolution of impact basins: Cooling, subsidence and thermal stress, *J. Geophys. Res., 90,* 12415-12433, 1985.

Bratt, S. R., S. C. Solomon, and J. W. Head, Subsurface heating during impact basin formation: Constraints from thermal contraction and thermal stress, in *Reports of Planetary Geology and Geophysics Program - 1985*, NASA TM 88383, 366-368, 1986.

Bratt, S. R., S. C. Solomon, J. W. Head, and C. H. Thurber, Mantle uplift beneath lunar basins: Clues to the understanding of basin formation, in *Lunar and Planetary Science XV*, 88-89, Lunar and Planetary Institute, Houston, Tex., 1984.

Bratt, S. R., S. C. Solomon, J. W. Head, and C. H. Thurber, The deep structure of lunar basins: Clues to the understanding of basin formation and modification, in *Reports of Planetary Geology and Geophysics Program - 1984*, NASA TM 87563, 491-493, 1985.

Bratt, S. R., S. C. Solomon, J. W. Head, and C. H. Thurber, The deep structure of lunar basins: Implications for basin formation and modification, *J. Geophys. Res., 90,* 3049-3064, 1985.

Church, S., J. W. Head, and S. C. Solomon, Multi-ringed basin interiors: Structure and early evolution of Oriantale, in *Lunar and Planetary Science XIII*, 98-99, Lunar and Planetary Institute, Houston, Tex., 1982.

Comer, R. P., Thick plate flexure, *Geophys. J. Roy. Astron. Soc., 72,* 101-114, 1983.

Comer, R. P., and S. C. Solomon, The Olympus Mons paradox: Why hasn't the Martian lithosphere failed under the load?, in *Lunar and Planetary Science XII*, 166-168, Lunar and Planetary Institute, Houston, Tex., 1981.

Comer, R. P., S. C. Solomon, and J. W. Head, Elastic lithospheric thickness on the Moon from mare tectonic features: A formal inversion, *Eos Trans. Amer. Geophys. Un., 60*, 393, 1979.

Comer, R. P., S. C. Solomon, and J. W. Head, Elastic lithosphere thickness on the Moon from mare tectonic features: A formal inversion, in *Proc. Lunar Planet. Sci. Conf. 10th*, 2441-2463, 1979.

Comer, R. P., S. C. Solomon, and J. W. Head, Thickness of the Martian lithosphere beneath volcanic loads: A consideration of time dependent effects, in *Lunar and Planetary Science XI*, 171-173, Lunar and Planetary Institute, Houston, Tex., 1980.

Comer, R. P., S. C. Solomon, and J. W. Head, Mars: Thickness of the lithosphere from the tectonic response to volcanic loads, *Rev. Geophys., 23*, 61-92, 1985.

Consolmagno, G. J., Ice-rich moons and the physical properties of ice, *J. Phys. Chem., 87*, 4204-4208, 1983.

Consolmagno, G. J., Resurfacing Saturn's satellites: Models of partial differentiation and expansion, *Icarus, 64*, 401-413, 1985.

Drew, W. A., The derivation of analytical formulae for certain 2-dimensional problems in viscous relaxation pertinent to the study of planetary topographical evolution, S. B. thesis, Massachusetts Institute of Technology, Cambridge, 83 pp., 1984.

Grimm, R. E., Metamorphism, fragmentation, and reassembly of chondrite parent bodies: A penecontemporaneous view, in *Lunar and Planetary Science XV*, 328, Lunar and Planetary Institute, Houston, Tex., 1984.

Grimm, R. E., Penecontemporaneous metamorphism, fragmentation, and reassembly of ordinary chondrite bodies, *J. Geophys. Res.*, 90, 2022-2028, 1985.

Grimm, R. E., I. Aspects of lithospheric evolution on Venus, II. Thermal and collisional histories of chondrite parent bodies, Ph.D. thesis, Massachusetts Institute of Technology, Cambridge, 329 pp., 1988.

Grimm, R. E., and H. Y. McSween, Jr., Water and the thermal history of the CM carbonaceous chondrite parent body, in *Lunar and Planetary Science XIX*, 427-428, Lunar and Planetary Institute, Houston, Tex., 1988.

Grimm, R. E., and H. Y. McSween, Jr., Water and the thermal evolution of carbonaceous chondrite parent bodies, *Icarus, 82*, 244-280, 1989.

Grimm, R. E., and S. C. Solomon, Tectonic tests of proposed polar wander paths for Mars and the Moon, in *Lunar and Planetary Science XVI*, 298-299, Lunar and Planetary Institute, Houston, Tex., 1985.

Grimm, R. E., and S. C. Solomon, Tectonic tests of proposed polar wander paths for Mars and the Moon, in *Reports of Planetary Geology and Geophysics Program - 1985*, NASA TM 88383, 378-380, 1986.

Grimm, R. E., and S. C. Solomon, Tectonic tests of proposed polar wander paths for Mars and the Moon, *Icarus, 65*, 110-121, 1986.

Grimm, R. E., and S. C. Solomon, Limits on modes of lithospheric heat transport on Venus from impact crater density, in *Lunar and Planetary Science XVIII*, 366-367, Lunar and Planetary Institute, Houston, Tex., 1987.

Grimm, R. E., and S. C. Solomon, Viscous relaxation of impact crater relief on Venus: Constraints on crustal thickness and thermal gradient, in *Lunar and Planetary Science XVIII*, 368-369, Lunar and Planetary Institute, Houston, Tex., 1987.

Grimm, R. E., and S. C. Solomon, Limits on modes of lithospheric heat transport on Venus from impact crater density, *Geophys. Res. Lett.*, *14*, 538-541, 1987.

Grimm, R. E., and S. C. Solomon, Limits on modes of lithospheric heat transport on Venus from impact crater density, in *Reports of Planetary Geology and Geophysics Program - 1987*, NASA TM 4041, 416-418, 1988.

Grimm, R. E., and S. C. Solomon, Viscous relaxation of impact crater relief on Venus: Constraints on crustal thickness and thermal gradient, in *Reports of Planetary Geology and Geophysics Program - 1987*, NASA TM 4041, 413-415, 1988.

Grimm, R. E., and S. C. Solomon, Generation and evolution of crust on Venus: Implications of viscous relaxation models, in *Lunar and Planetary Science XIX*, 429-430, Lunar and Planetary Institute, Houston, Tex., 1988.

Grimm, R. E., and S. C. Solomon, Relaxation of topographic relief on Venus: Implications for an active planet, *Eos Trans. Amer. Geophys. Un.*, *69*, 1294-1295, 1988.

Grimm, R. E., and S. C. Solomon, Viscous relaxation of impact crater relief on Venus: Constraints on crustal thickness and thermal gradient, *J. Geophys. Res.*, *93.*, 11911-11929, 1988.

Grimm, R. E., and S. C. Solomon, Tests of crustal divergence models for Aphrodite Terra, Venus, *J. Geophys. Res.*, *94*, 12103-12131, 1989.

Grimm, R. E., S. C. Solomon, L. S. Crumpler, and J. W. Head, Tests of crustal divergence models for Venus, *Eos Trans. Amer. Geophys. Un.*, *68*, 1338, 1987.

Grimm, R. E., S. C. Solomon, L. S. Crumpler, and J. W. Head, Tests of crustal divergence models for Venus, in *Lunar and Planetary Science XIX*, 431-432, Lunar and Planetary Institute, Houston, Tex., 1988.

Grimm, R. E., and S. W. Squyres, Spectral analysis of groove spacing on Ganymede, in *Lunar and Planetary Science XV*, 329-330, Lunar and Planetary Institute, Houston, Tex., 1984.

Grimm, R. E., and S. W. Squyres, Spectral analysis of groove spacing on Ganymede, *J. Geophys. Res.*, *90*, 2013-2021, 1985.

Hall, J. L., Processes leading to the formation of tectonic features on the Moon and Mars, Ph.D. thesis, Massachusetts Institute of Technology, Cambridge, 308 pp., 1985.

Hall, J. L., Geology of Venus, *Physics Today*, *41*, no. 1, 537-538, 1987.

Hall, J. L., J. W. Head, and S. C. Solomon, Lunar floor fractured craters: Quantitative tests of hypotheses for their origin, in *Reports of Planetary Geology Program*, 1978-1979, NASA TM 80339, 129-131, 1979.

Hall, J. L., J. W. Head, and S. C. Solomon, Lunar floor fractured craters: The relative importance of isostatic relaxation and uplift by volcanic intrusion, in *Lunar and Planetary Science XI*, 385-387, Lunar and Planetary Institute, Houston, Tex., 1980.

Hall, J. L., and S. C. Solomon, Lithospheric loading and tectonics of the lunar irregular maria, in *Lunar and Planetary Science XVII*, 305-306, Lunar and Planetary Institute, Houston, Tex., 1986.

Hall, J. L., and S. C. Solomon, Lithospheric loading and tectonics of the lunar irregular maria, in *Reports of Planetary Geology and Geophysics Program - 1986*, NASA TM 89810, 464-466, 1987.

Hall, J. L., S. C. Solomon, and J. W. Head, Lunar floor fractured craters: Evidence for viscous relaxation of crater topography, in *Lunar and Planetary Science XII*, 389-391, Lunar and Planetary Institute, Houston, Tex., 1981.

Hall, J. L., S. C. Solomon, and J. W. Head, Lunar floor-fractured craters: Evidence for viscous relaxation of crater topography, *J. Geophys. Res.*, *86*, 9537-9552, 1981.

Hall, J. L., S. C. Solomon, and J. W. Head, Elysium region, Mars: Tests of lithospheric loading models for the formation of tectonic features, in *Lunar and Planetary Science XV*, 341-342, Lunar and Planetary Institute, Houston, Tex., 1984.

Hall, J. L., S. C. Solomon, and J. W. Head, Elysium region, Mars: Tests of lithospheric loading models for the formation of tectonic features, in *Reports of Planetary Geology and Geophysics Program - 1984*, NASA TM 87563, 500-502, 1985.

Hall, J. L., S. C. Solomon, and J. W. Head, Elysium region, Mars: Tests of lithospheric loading models for the formation of tectonic features, *J. Geophys. Res.*, *91*, 11377-11392, 1986.

Hall, J. L., S. C. Solomon, J. W. Head, and P. J. Mouginis-Mark, Elysium region, Mars: Characterization of tectonic features, in *Lunar and Planetary Science XIV*, 275-276, Lunar and Planetary Institute, Houston, Tex., 1983.

Hall, J. L., S. C. Solomon, J. W. Head, and P. J. Mouginis-Mark, Elysium region, Mars: Characterization of tectonic features, in *Reports of Planetary Geology Program - 1983*, NASA TM 86246, 291-292, 1984.

Head, J. W., and S. C. Solomon, Lunar basin structure: Possible influence of variations in lithospheric thickness, in *Lunar and Planetary Science XI*, 421-423, Lunar and Planetary Institute, Houston, Tex., 1980.

Head, J. W., and S. C. Solomon, Impact basins: Stages in basin formation and evolution, in *Lunar and Planetary Science XII*, 424-426, Lunar and Planetary Institute, Houston, Tex., 1981.

Head, J. W., and S. C. Solomon, Impact basins: Stages in basin formation and evolution, in *Reports of Planetary Geology Program - 1981*, NASA TM 84211, 111-113, 1981.

Head, J. W., and S. C. Solomon, Tectonic evolution of the terrestrial planets, *Science*, *213*, 62-76, 1981.

Head, J. W., and S. C. Solomon, Topography of Venus and Earth: A test for the presence of plate tectonics, *Eos Trans. Amer. Geophys. Un.*, *62*, 386, 1981.

Head, J. W., and S. C. Solomon, Tectonic evolution of the terrestrial planets, *Eos Trans. Amer. Geophys. Un., 63*, 1293, 1982.

Head, J. W., and S. C. Solomon, Tectonic style and evolution of the terrestrial planets, *Abstracts, 27th International Geological Congress, Moscow, 8*, 290, 1984.

Head, J. W., S. C. Solomon, and J. L. Whitford-Stark, Oceanus Procellarum region: Evidence for an anomalously thin early lunar lithosphere, in *Lunar and Planetary Science XI*, 424-425, Lunar and Planetary Institute, Houston, Tex., 1980.

Head, J. W., L. Wilson, and S. C. Solomon, Basaltic volcanism on the terrestrial planets and its relationship to thermal evolution, *Eos. Trans. Amer. Geophys. Un., 62*, 1079, 1981.

Head, J. W., S. E. Yuter, and S. C. Solomon, Topography of Venus and Earth: A test for the presence of plate tectonics, in *Lunar and Planetary Science XII*, 430-432, Lunar and Planetary Institute, Houston, Tex., 1981.

Head, J. W., S. E. Yuter, and S. C. Solomon, A comparison of the topography of Venus and Earth: A test for the presence of plate tectonics, *Amer. Sci., 69*, 614-623, 1981.

Hsui, A. T., and S. C. Solomon, Effects of viscosity and melting relations on planetary thermal history models and magma generation, in *Papers Presented to the Second Inter-Team Meeting, Basaltic Volcanism Study Project*, pp. 32-34, Lunar Science Institute, Houston, Tex., 1977.

Huang, P. Y., and S. C. Solomon, Thermal history and lithospheric thermal stress for Ganymede and Callisto, in *Lunar and Planetary Science XIII*, 344-345, Lunar and Planetary Institute, Houston, Tex., 1982.

Levy, E. H., and S. C. Solomon, The science of planetary exploration, in *The National Research Council in 1979, Current Issues and Studies*, Nat. Acad. Sci., Washington, D.C., pp. 117-137, 1979.

Matsui, T., and Y. Abe, Evolution of an impact-induced atmosphere and magma ocean on the accreting Earth, *Nature, 319*, 303-305, 1986.

Matsui, T., and Y. Abe, Impact-induced atmospheres and oceans on Earth and Venus, *Nature, 322*, 526-528, 1986.

Matsui, T., and Y. Abe, Evolutionary tracks of the terrestrial planets, *Earth Moon Planets, 39*, 207-214, 1987.

McGovern, P. J., and G. Schubert, Thermal evolution of the Earth: Effects of volatile exchange between atmosphere and interior, in *Abstracts Presented to the Topical Conference on the Origin of the Earth*, p. 56, Lunar and Planetary Institute, Houston, Tex., 1988.

McGovern, P. J., and G. Schubert, Thermal evolution of the Earth: Effects of volatile exchange between atmosphere and interior, *Earth Planet. Sci. Lett., 96*, 27-37, 1989.

McGovern, P. J., and S. C. Solomon, Influence of volatile loss on the mantle temperature of Venus, in *Lunar and Planetary Science XX*, 669-670, Lunar and Planetary Institute, Houston, Tex., 1989.

McGovern, P. J., and S. C. Solomon, Influence of volatile loss on the mantle temperature of Venus, in *Reports of Planetary Geology and Geophysics Program - 1988*, NASA TM 4130, 39-40, 1989.

Mouginis-Mark, P. J., L. Wilson, J. W. Head, S. H. Brown, J. L. Hall, and K. D. Sullivan, Elysium Planitia, Mars: Regional geology, volcanology, and evidence for volcano-ground ice interactions, *Earth Moon Planets, 30*, 149-173, 1984.

Namiki, N., and T. Matsui, Numerical N-body simulations of the accretion process of the terrestrial planets, *Eos Trans. Amer. Geophys. Un., 69*, 1286, 1988.

Namiki, N., and T. Matsui, Numerical N-body simulation of the accretion process of the terrestrial planets, in *Lunar and Planetary Science XX*, 758-759, Lunar and Planetary Institute, Houston, Tex., 1989.

Pollack, J. B., and G. Consolmagno, Origin and evolution of the Saturn system, in *Saturn*, edited by T. Gehrels and M. S. Matthews, Univ. Arizona Press, Tucson, 811-866, 1984.

Schubert, G., S. C. Solomon, D. L.Turcotte, M. J. Drake and N. H. Sleep, Origin and thermal evolution of Mars, in *Mars*, edited by H. Kieffer, B. Jakosky, C. Snyder, and M. S. Matthews, Univ. Arizona Press, in press, 1990.

Schubert, G., D. L. Turcotte, S. C. Solomon, and N. Sleep, Planetary and satellite atmospheres and interiors: Evolution of the coupled system, in *Origin and Evolution of Planetary and Satellite Atmospheres, Program and Abstracts*, p. 50, University of Arizona, Tucson, 1987.

Schubert, G., D. L. Turcotte, S. C. Solomon, and N. Sleep, Coupled evolution of the atmospheres and interiors of planets and satellites, in *Origin and Evolution of Planetary and Satellite Atmospheres*, edited by S. K. Atreya, J. B. Pollack, and M. S. Matthews, University of Arizona Press, Tucson, Ariz., 450-483, 1989.

Schubert, G., D. L. Turcotte, S. C. Solomon, N. Sleep, and M. J. Drake, Origin and thermal evolution of Mars, in *Program and Abstracts, Fourth International Conference on Mars*, pp. 50-51, University of Arizona, Tucson, 1989.

Simonds, C. H., P. H. Schultz, and S. C. Solomon, Comparison of Mercury and the Moon: A conference, *Eos Trans. Amer. Geophys. Un., 59*, 43-48, 1978.

Solomon, S. C., The relationship between crustal tectonics and internal evolution in the Moon and Mercury, in *Papers Presented to the Conference on Comparisons of Mercury and the Moon*, 32, Lunar Science Institute, Houston, Tex., 1976.

Solomon, S. C., Heat, stretch and erupt: The relationships among global thermal evolution, crustal tectonics and surface volcanism on the terrestrial planets, in *Reports of Planetary Geology Program*, 1976-1977, NASA TM X-3511, 20-21, 1977.

Solomon, S. C., Planetary interiors, *Geotimes, 22*, n. 5, 16-18, 1977.

Solomon, S. C., On volcanism and thermal tectonics on one-plate planets, in *Papers Presented to the Second Inter-Team Meeting, Basaltic Volcanism Study Project*, pp. 58-60, Lunar Science Institute, Houston, Tex., 1977.

Solomon, S. C., Put up or shut up: What do we really know about terrestrial interiors?, *Bull. Amer. Astron. Soc., 9*, 542, 1977.

Solomon, S. C., The relationship between crustal tectonics and internal evolution in the Moon and Mercury, *Phys. Earth Planet. Inter.*, *15*, 135-145, 1977.

Solomon, S. C., When you're hot you're hot: Core formation, convection and energy sources in the terrestrial planets, *Eos Trans. Amer. Geophys. Un.*, *58*, 1128, 1977.

Solomon, S. C., On volcanism and thermal tectonics on one-plate planets, *Geophys. Res. Lett.*, *5*, 461-464, 1978.

Solomon, S. C., Volcanism and crustal tectonics as consequences of thermal history for the terrestrial planets, *Eos Trans. Amer. Geophys. Un.*, *59*, 310, 1978.

Solomon, S. C., Differentiation of cores and crusts of the terrestrial planets: Lessons for the Earth?, *Abstracts with Programs*, 10, 495, Geol. Soc. Amer., Boulder, Colo., 1978.

Solomon, S. C., Formation, history, and energetics of cores in the terrestrial planets, *Phys Earth Planet. Inter.*, *19*, 168-182, 1979.

Solomon, S. C., Geophysical evolution of the lunar crust and lithosphere, in *Papers Presented to the Conference on the Lunar Highlands Crust*, pp. 154-156, Lunar and Planetary Institute, Houston, Tex., 1979.

Solomon, S. C., Differentiation of crusts and cores of the terrestrial planets: Lessons for the early Earth?, *Precambrian Res.*, *10*, 177-194, 1980.

Solomon, S. C., The geophysics of Mars: Whence the Tharsis plateau?, *Nature*, *294*, 304-305, 1981.

Solomon, S. C., The internal evolution of Venus and the Galilean satellites, *Nature*, *298*, 15-16, 1982.

Solomon, S. C., Global tectonics: The planetary perspective, in *Abstracts of Papers of the 149th Annual Meeting*, p. 13, Amer. Assoc. Advance. Sci., Washington, D.C., 1983.

Solomon, S. C., The elastic lithosphere: Some relationships among flexure, depth of faulting, lithospheric thickness, and thermal gradient, in *Lunar and Planetary Science XVI*, 752-753, Lunar and Planetary Institute, Houston, Tex., 1985.

Solomon, S. C., Lithospheric extension and volcanism on the solid planets and satellites: A geophysical view, *Abstracts with Programs*, *17*, 722, Geol. Soc. Amer., Boulder, Colo., 1985.

Solomon, S. C., Secular cooling of the Earth as a source of intraplate stress, *Eos Trans. Amer. Geophys. Un.*, *66*, 1098, 1985.

Solomon, S. C., On the early thermal state of the Moon, in *Origin of the Moon*, edited by W.K. Hartmann, R.J. Phillips, and G. J. Taylor, Lunar and Planetary Institute, Houston, Tex., pp. 435-452, 1986.

Solomon, S. C., Secular cooling of the Earth as a source of intraplate stress, in *Lunar and Planetary Science XVII*, 811-812, Lunar and Planetary Institute, Houston, Tex., 1986.

Solomon, S. C., The elastic lithosphere: Some relationships among flexure, depth of faulting, lithospheric thickness, and thermal gradient, in *Reports of Planetary Geology and Geophysics Program - 1985*, NASA TM 88383, 397-399, 1986.

Solomon, S. C., Secular cooling of the Earth as a source of intraplate stress, in *Reports of Planetary Geology and Geophysics Program - 1986*, NASA TM 89810, 455-457, 1987.

Solomon, S. C., Secular cooling of the Earth as a source of intraplate stress, *Earth Planet. Sci. Lett.*, *83*, 153-158, 1987.

Solomon, S. C., Geophysics and tectonics of Mars, *Abstracts with Programs*, *20*, A83, Geol. Soc. Amer., Boulder, Colo., 1988.

Solomon, S. C., Lunar geology: Ironing out the wrinkles, *Nature*, 342, 477-478, 1989.

Solomon, S. C., T. J. Ahrens, P. Cassen, A. T. Hsui, J. W. Minear, R. T. Reynolds, N. H. Sleep, D. W. Strangway, and D. L. Turcotte, Thermal histories of the terrestrial planets, in *Basaltic Volcanism on the Terrestrial Planets*, Pergamon, New York, 1129-1234, 1981.

Solomon, S. C., S. R. Bratt, R. P. Comer, and J. W. Head, The evolution of multi-ringed basins: Cooling, thermal stress, and relaxation of topography, in *Reports of Planetary Geology Program - 1980*, NASA TM 82385, 116-118, 1980.

Solomon, S. C., S. R. Bratt, and J. W. Head, Implications of new structural models for lunar basins: Age-dependence of basin modification processes, in *Lunar and Planetary Science XV*, 804-805, Lunar and Planetary Institute, Houston, Tex., 1984.

Solomon, S. C., R. P. Comer, and J. W. Head, Viscous relaxation of lunar basin topography: Evidence for hemispherical asymmetry in pre-Nectarian crustal temperature, in *Lunar and Planetary Science XIII*, 748-749, Lunar and Planetary Institute, Houston, Tex., 1982.

Solomon, S. C., R. P. Comer, and J. W. Head, The evolution of impact basins: Viscous relaxation of topographic relief, *J. Geophys. Res.*, *87*, 3975-3992, 1982.

Solomon, S. C., R. P. Comer, S. K. Stephens, and J. W. Head, Viscous relaxation of impact basin topography: Implications for the Moon and Venus, in *Reports of Planetary Geology - 1981*, NASA TM 84211, 114-116, 1981.

Solomon, S. C., and E. D. Duxbury, A test of the hypothesis that impact-induced fractures are preferred sites for later tectonic activity, in *Lunar and Planetary Science XVII*, 813-814, Lunar and Planetary Institute, Houston, Tex., 1986.

Solomon, S. C., and E. D. Duxbury, A test of the hypothesis that impact-induced fractures are preferred sites for later tectonic activity, in *Reports of Planetary Geology and Geophysics Program - 1986*, NASA TM 89810, 458-460, 1987.

Solomon, S. C., and E. D. Duxbury, A test of the longevity of impact-induced faults as preferred sites for later tectonic activity, in *Proc. Lunar Planet. Sci. Conf. 17th, J. Geophys. Res.*, *92*, E759-E768, 1987.

Solomon, S. C., and R. E. Grimm, Mechanisms of lithospheric heat transport on Venus: Constraints from impact crater density, *V-Gram*, *13*, 10-14, 1987.

Solomon, S. C., and R. E. Grimm, Tectonic activity on Venus, *Nature*, *331*, 305-306, 1988.

Solomon, S. C., and J. W. Head, Vertical movement in mare basins: Relation to mare emplacement, basin tectonics, and lunar thermal history, in *Lunar and Planetary Science IX*, 1083-1085, Lunar and Planetary Institute, Houston, Tex., 1978.

Solomon, S. C., and J. W. Head, The tectonics of filled basins on the terrestrial planets, in *Reports of Planetary Geology Program, 1977-1978*, NASA TM 79729, 66-68, 1978.

Solomon, S. C., and J. W. Head, Characteristics and evolution of the lunar lithosphere from the deformation of mascon mare basins, in *Lunar and Planetary Science X*, 1140-1142, Lunar and Planetary Institute, Houston, Tex., 1979.

Solomon, S. C., and J. W. Head, Vertical movement in mare basins: Relation to mare emplacement, basin tectonics, and lunar thermal history, *J. Geophys. Res.*, *84*, 1667-1682, 1979.

Solomon, S. C., and J. W. Head, Lunar mascon basins: Lava filling, tectonics, and evolution of the lithosphere, *Rev. Geophys. Space Phys.*, *18*, 107-141, 1980.

Solomon, S. C., and J. W. Head, Tharsis: An alternative explanation, in *Reports of Planetary Geology Program*, 1979-1980, NASA TM 81776, 71-73, 1980.

Solomon, S. C., and J. W. Head, Tharsis province: Uplift by anomalous mantle, or concentration of tectonism and volcanism in a locally thin lithosphere, in *Lunar and Planetary Science XI*, 1063-1065, Lunar and Planetary Institute, Houston, Tex., 1980.

Solomon, S. C., and J. W. Head, The evolution of multi-ringed basins: Viscoelastic relaxation of topographic relief, in *Lunar and Planetary Science XII*, 1023-1025, Lunar and Planetary Institute, Houston, Tex., 1981.

Solomon, S. C., and J. W. Head, Are there impact basins on Venus?, *Eos Trans. Amer. Geophys. Un.*, *62*, 386, 1981.

Solomon, S. C., and J. W. Head, Mechanisms for lithospheric heat transfer on Venus: Implications for tectonic style and volcanism, in *Lunar and Planetary Science XIII*, 750-751, Lunar and Planetary Institute, Houston, Tex., 1982.

Solomon, S. C., and J. W. Head, Early crustal genesis: Physical and tectonic evolution, *Eos Trans. Amer. Geophys. Un.*, *63*, 366, 1982.

Solomon, S. C., and J. W. Head, Mechanisms for lithospheric heat transfer on Venus: Predictions for surface volcanic and tectonic features, in *Reports of Planetary Geology - 1982*, NASA TM 85127, 90-92, 1982.

Solomon, S. C., and J. W. Head, Mechanisms for lithospheric heat transport on Venus: Implications for tectonic style and volcanism, *J. Geophys. Res.*, *87*, 9236-9246, 1982.

Solomon, S. C., and J. W. Head, Evolution of the Tharsis province of Mars: The importance of heterogeneous lithospheric thickness and volcanic construction, *J. Geophys. Res.*, *87*, 9755-9774, 1982.

Solomon, S. C., and J. W. Head, Is there plate recycling on Venus?: A test of the hypothesis using topographic and radar backscatter data, *Eos Trans. Amer. Geophys. Un.*, *63*, 1092, 1982.

Solomon, S. C., and J. W. Head, Venus banded terrain: Evaluation of tectonic models for the origin of banding, in *Lunar and Planetary Science XIV*, 723-724, Lunar and Planetary Institute, Houston, Tex., 1983.

Solomon, S. C., and J. W. Head, Planetary volcanism and tectonics: Some connecting links, *Abstracts with Programs, 15*, Geol. Soc. Amer., Boulder, Colo., 691, 1983.

Solomon, S. C., and J. W. Head, The tectonic evolution of the terrestrial planets, *Terra Cognita*, 4, 74, 1984.

Solomon, S. C., and J. W. Head, Rift structures on Venus: Implications of a lithospheric stretching model, in *Lunar and Planetary Science XV*, 806-807, Lunar and Planetary Institute, Houston, Tex., 1984.

Solomon, S. C., and J. W. Head, Venus banded terrain: Evaluation of tectonic models for the origin of banding, in *Reports of Planetary Geology Program - 1983*, NASA TM 86246, 74-75, 1984.

Solomon, S. C., and J. W. Head, Venus banded terrain: Tectonic models for band formation and their relationship to lithospheric thermal structure, *J. Geophys. Res., 89*, 6885-6897, 1984.

Solomon, S. C., and J. W. Head, Venus tectonics: Geophysical models and implications, *Abstracts, COSPAR 25th Penary Meeting*, Graz, Austria, 69, 1984.

Solomon, S. C., and J. W. Head, Rift systems on Venus: An assessment of mechanical and thermal models, in *Papers Presented to the Conference on Heat and Detachment in Crustal Extension on Continents and Planets*, 138-141, Lunar and Planetary Institute, Houston, Tex., 1985.

Solomon, S. C., and J. W. Head, Venus chasmata: A lithospheric stretching model, in *Reports of Planetary Geology and Geophysics Program - 1984*, NASA TM 87563, 117-118, 1985.

Solomon, S. C., and J. W. Head, Heterogeneities in the thickness of the elastic lithosphere of Mars: Constraints on thermal gradients, crustal thickness, and internal dynamics, in *Abstracts for the MEVTV-LPI Workshop: Early Tectonic and Volcanic Evolution of Mars*, 54-56, Lunar and Planetary Institute, Houston, Tex., 1988.

Solomon, S. C., and J. W. Head, Lithospheric flexure beneath the Freyja Montes foredeep, Venus, *Eos Trans. Amer. Geophys. Un., 69*, 1295, 1988.

Solomon, S. C., and J. W. Head, Estimating lithospheric thermal gradient on Mars from elastic lithosphere thickness: New constraints on heat flow and mantle dynamics, in *Lunar and Planetary Science XX*, 1030-1031, Lunar and Planetary Institute, Houston, Tex., 1989.

Solomon, S. C., and J. W. Head, Lithospheric flexure beneath the Freyja Montes foredeep, Venus: Constraints on lithospheric thermal gradient and heat flow, *Lunar and Planetary Science XX*, 1032-1033, Lunar and Planetary Institute, Houston, Tex., 1989.

Solomon, S. C., and J. W. Head, Estimating lithospheric thermal gradient on Mars from elastic lithosphere thickness: New constraints on heat flow and mantle dynamics, in *Reports of Planetary Geology and Geophysics Program - 1988*, 203-205, 1989.

Solomon, S. C., and J. W. Head, Lithospheric flexure beneath Freyja Montes foredeep, Venus: Constraints on lithospheric thermal gradient and heat flow, in *Reports of Planetary Geology and Geophysics Program - 1988*, NASA TM 4130, 43-45, 1989.

Solomon, S. C., and J. W. Head, Heterogeneities in the thickness of the elastic lithosphere of Mars: Constraints on heat flow and internal dynamics, *J. Geophys. Res.*, in press, 1990.

Solomon, S. C., J. W. Head, and R. P. Comer, Thickness of the Martian lithosphere from tectonic features: Evidence for lithospheric thinning beneath volcanic provinces, in *Reports of Planetary Geology Program, 1978-1979*, NASA TM 80339, 60-62, 1979.

Solomon, S. C., J. W. Head, and R. P. Comer, From Tharsis to Tholus: Evolution of the Martian lithosphere and its response to volcanic loads, in *Papers Presented to the Third International Colloquium on Mars*, 244-246, in Lunar and Planetary Institute, Houston, Tex., 1981.

Solomon, S. C., and L. Meinke, Longevity of impact-induced faults and preferred sites for later tectonic activity: A further terrestrial test, in *Lunar and Planetary Science XIX*, 1105-1106, Lunar and Planetary Science Institute, Houston, Tex., 1988.

Solomon, S. C., and L. Meinke, Longevity of impact-induced faults as preferred sites for later tectonic activity: An update, in *Reports of Planetary Geology and Geophysics Program - 1987*, NASA TM 4041, 465-466, 1988.

Solomon, S. C., W. L. Sjogren, and S. R. Bratt, The structure of Isidis basin, Mars, from gravity anomalies, in *Lunar and Planetary Science XIV*, 725-726, Lunar and Planetary Institute, Houston, Tex., 1983.

Solomon, S. C., S. K. Stephens, and J. W. Head, Viscous relaxation of impact basin topography on Venus, in *Lunar and Planetary Science XIII*, 752-753, Lunar and Planetary Institute, Houston, Tex., 1982.

Solomon, S. C., S. K. Stephens, and J. W. Head, On Venus impact basins: Viscous relaxation of topographic relief, *J. Geophys. Res.*, *87*, 7763-7771, 1982.

Stephens, S. K., S. C. Solomon, and J. W. Head, On the age of Venus highland topography: Constraints from the viscous relaxation of relief, in *Lunar and Planetary Science XIV*, 747-748, Lunar and Planetary Institute, Houston, Tex., 1983.

Yomogida, K., and T. Matsui, Physical properties of ordinary chondrites and their implications, *Meteoritics*, *18*, 430-431, 1983.

Yomogida, K., and T. Matsui, Physical properties of ordinary chondrites, *J. Geophys. Res.*, *88*, 9513-9533, 1983.

Yomogida, K., and T. Matsui, Multiple parent bodies of ordinary chondrites, *Earth Planet. Sci. Lett.*, *68*, 34-42, 1984.

Zimbelman, J. R., S. C. Solomon, and V. L. Sharpton, editors, *MEVTV Workshop on Nature and Composition of Surface Units on Mars*, *LPI Tech. Rep. 88-05*, Lunar and Planetary Institute, Houston, Tex., 144 pp., 1988.